Mars Small Spacecraft Studies: Overview

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Abstract— **NASA's Mars Exploration Program is studying a potential Mars Sample Return (MSR) campaign consisting of a series of missions over the next decade that would return samples collected at Mars for analyses in terrestrial laboratories. It is anticipated that during such a campaign, many in the Mars science community would seek to continue high-priority science investigations in parallel to those provided by geological and astrobiological sample return investigations. To respond to this anticipated desire of the science community, JPL is performing a study of small spacecraft mission concepts to Mars that could bridge the gap between MSR and other desired science investigations at Mars. The goal of the study is to utilize smaller, affordable missions in performing high-priority science investigations as defined in the National Academy of Sciences Decadal Survey, Mars Exploration Program Analysis Group (MEPAG) goals, and Human Exploration and Operations (HEO) Strategic Knowledge Gaps. The study targets the use of small spacecraft with greater science capability than currently achievable with CubeSats. The target spacecraft wet mass is approximately 100 to 350 kilograms. Methods of access to Mars considered in this study include a self-propelled transit from Earth geosynchronous transfer orbit (GTO) to Mars as a secondary payload in a rideshare configuration. The study investigates mission concepts, science objectives, mission designs, concept of operations, enhancing technologies, and mission costs, along with launch vehicle interfaces. The cost estimates of the mission concepts studied range from below $100 million to less than $300 million for development through launch. This paper concludes with an outline of several examples of small spacecraft mission concepts to Mars that demonstrate significant scientific capability, are technically feasible, and fit within the desired cost range.**

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1. MOTIVATION

Mars Sample Return (MSR) campaign is a proposed series of missions to return samples from the surface of Mars to Earth. The missions would use robotic systems and a Mars ascent rocket to collect samples of Martian rocks, soils, and atmosphere and return back to the Earth for detailed chemical and physical analysis [1]. If approved, this campaign would capture a significant portion of the Mars Exploration Program budget leaving the Mars science community with a desire to conduct other high-priority science investigations. To respond to this anticipated desire of the science community; Jet Propulsion Laboratory (JPL) is performing a study of Mars small spacecraft mission concepts that could bridge the gap between MSR and other desired science investigations.

Traditionally, for science missions to Mars, NASA has commissioned highly capable multi-instrument spacecraft that launched as primary payloads on the evolvable expendable launch vehicle (EELV). One of the effective ways to lower mission costs is to reduce the weight of the spacecraft, including the mission spacecraft sensors [2]. Over the past decade, there has been a significant growth of commercial small satellite suppliers and service providers, which has created an industry for lower-cost space-qualified hardware. Launch cost for small spacecraft could be up to an order of magnitude lower than those for primary payloads. Combination of lower mission and launch costs provides an emerging opportunity for small spacecraft to reach Mars on significantly reduced costs without compromising science quality.

Objectives

The purpose of the study is to determine the technical feasibility of sending a small spacecraft to Mars to conduct compelling science for a cost target below $300 million. The approach of the study focused on three areas:

- High-priority science investigations consistent with MEPAG goals that could be performed by small spacecraft.
- Method of transport of small spacecraft from Earth to Mars.
- Technical feasibility and mission cost of small spacecraft mission concepts.

The mission concepts studied are science driven, with goals traceable to the Decadal Survey, Mars Exploration Program Analysis Group (MEPAG, see figure 1) goals, Human Exploration and Operations Strategic Knowledge Gaps (HEO SKG's).

For the purposes of the study, small spacecraft will be defined to have a dry mass < 300 kg, meet a cost target < $300 million, and consists of orbiters and landers.

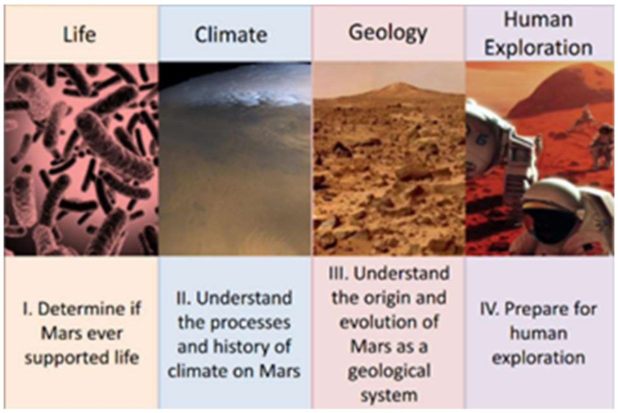


Figure 1: Mars Exploration Program Analysis Group (MEPAG) primary goals [3].

2. MARS SMALL SPACECRAFT SCIENCE

The goal of our study was to identify compelling science investigations (see figure 2) that are especially suited for small spacecraft. Of special importance are science goals that are related to (1) global observations and global context, allowing the derivation of a 3D map of Mars properties from orbit and on ground (3D networks and "mini-scouts") and particularly (2) global 4D (3D in space + time = 4D) observations of fast varying processes with changes occurring over periods of less than a few sols. The latter does not only provide a global context but would allow to constrain causality between processes on the planet. The two examples below highlight that 3D and 4D observations were a game changer for science on Earth, allowing to understand the deeper causes, reactions, and feedbacks between global processes and characteristics.

Trace Gas Localization	Exogenic influx (Meteors)	4D weather monitoring
Groundwater	EM fields (lightning, dust devils, ...)	4D Cloud Properties
4D Wind Monitoring	Moons of Mars	4D Radiation Science
3D Surface Mineralogy	3D Surface Magnetometry	Gravimetry

Figure 2: Possible science investigations for Mars small spacecraft concepts.

High Orbit Science

An opportunity of particular interest is an areostationary orbit, which is the Martian equivalent to a geostationary orbit, at 17,032 km above the Martian equatorial surface. Such an orbit will allow to continuously monitor the same surface area. Classic orbiters fly at high speed across the Martian surface and do not frequently cover the same regions. For example, ExoMars Trace Gas Orbiter (TGO) is currently sweeping Mars in the search for trace gases such as methane. However, a quasi-global coverage is only achieved in about one month for ExoMars TGO, too late to observe where such gases emerge, react, and disappear. To understand the sources and sinks of trace gases such as water, methane, and oxygen, climatic changes on diurnal timescales, radiation interactions with the atmosphere, the influx of exogenic particles (e.g., meteorites), we need to provide instantaneous global coverage over an unchanged large surface area, and hence have to turn to an areostationary orbit.

Surface and Subsurface Science

Reaching the surface of Mars and exploring the Martian subsurface is a holy grail of Mars science, especially as the National Academy of Sciences recent report on the strategy for the search for life in the universe calls for global access to the Mars subsurface [4]. Some of the key questions related to that would be:

- Is there liquid water in the subsurface, what is its chemistry?
- Which questions could be answered by mini-EM sounders (using induction) and B-field sensor assets on ground and in orbit?
- What is the spatial and temporal variability in key properties across the surface and subsurface, such as volatile exchange between surface and subsurface, outgassing, condensation, EM field, dust evolution, humidity, etc.?
- Which questions could be addressed with gas sniffers, tunable laser spectrometers, EM field sensors (e.g., fluxgate sensors), weather stations,

and impedance measurements?

3. Launch and Mission Design

The study focused on three different methods to get access to Mars (see figure 3).

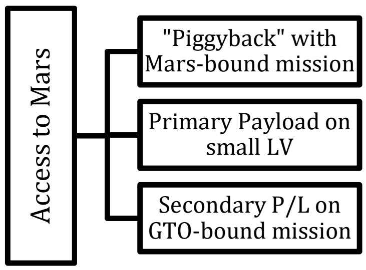


Figure 3: Considered options for small spacecraft to access Mars.

The first method is for the spacecraft to be carried as a “piggyback” with an existing mission to Mars. This rideshare configuration would vary depending upon the payload adapter or method of attachment. The deliverable mass to Mars is mission specific and is dependent upon the excess capability of the launch vehicle and constraints set by the primary spacecraft. Other constraints levied by the primary spacecraft include thermal protection, data availability, electrical power data during the cruise as well as the limitations on the deployment sequence. Perhaps, the largest limitation of the piggyback method is the relatively low frequency of launch opportunity which is set by a few Mars-bound mission. This method is less frequent but should be considered for future missions.

The second method is to launch as a primary payload on a small launch vehicle such as the Firefly Alpha, which has a target performance of 1,000 kg to low earth orbit (LEO) [5]. Starting from LEO, a solid rocket motor could act as a third stage to boost the payload to a higher orbit or escape, with the size determined by the specific mission design. The study of this method is still ongoing; the approaches and results are not included in this paper.

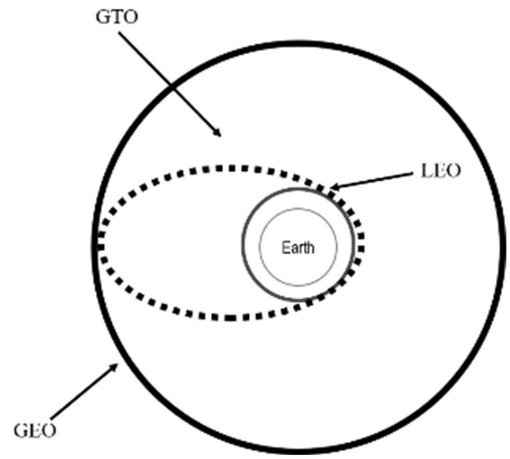


Figure 4: Geostationary Transfer Orbit (GTO)

The last method is for the spacecraft to be accommodated by a commercial, military, or NASA launch that reaches geostationary transfer orbit (GTO) or beyond (see figure 4). The typical launch configuration usually consists of a secondary payload that is attached to an EELV secondary payload adapter (ESPA). The primary payload is then stacked above the ESPA ring with a primary payload adapter, (see figure 5). After launch, the primary spacecraft (s/c) gets jettisoned, which is followed on by the separation of the Mars-bound s/c. This method of rideshare differs from the first method because the destination of the rideshare spacecraft concept is independent of the final destination of the primary mission.

A survey of Delta IV, Altas V, and Falcon 9 (all ELLV), launch data dated back to 2002, shows that 50% of all launches go to geosynchronous orbit. In the last 5 years, on average, at least 10 launches per year went to GTO. Preliminary results show that many have excess capability to support a secondary payload. This method is the most favorable because it allows frequent access to Mars, exceeds the spacecraft mass constraint, and the process is well documented by rideshare brokers and integrators.

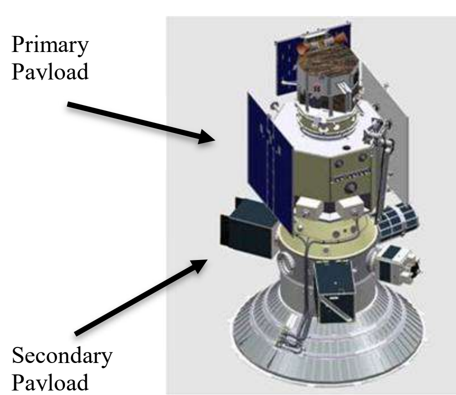


Figure 5: Illustration of the Space Test Payload (STP-1), first test flight of the ESPA ring [6].

The various stakeholders for rideshare are the primary payload, the secondary payload, the payload adapter, the launch vehicle, the integrator, and the broker, shown in figure 6. Our study surveyed each of the stakeholders, the policies, and processes for being a rideshare payload. The US Air Force plays a central role in setting standards for rideshare of secondary payloads and has published the rideshare user's guide (RUG) [7] for being co-manifested with Air Force missions.

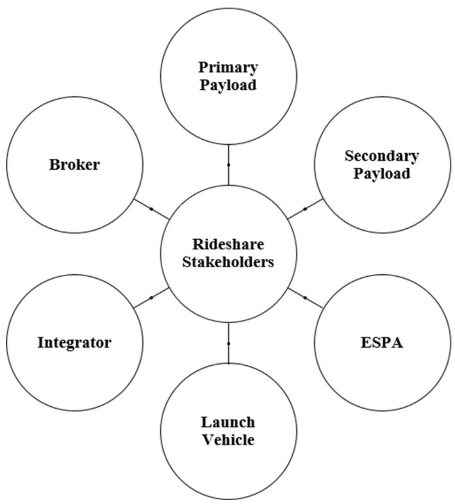


Figure 7: Rideshare Stakeholders

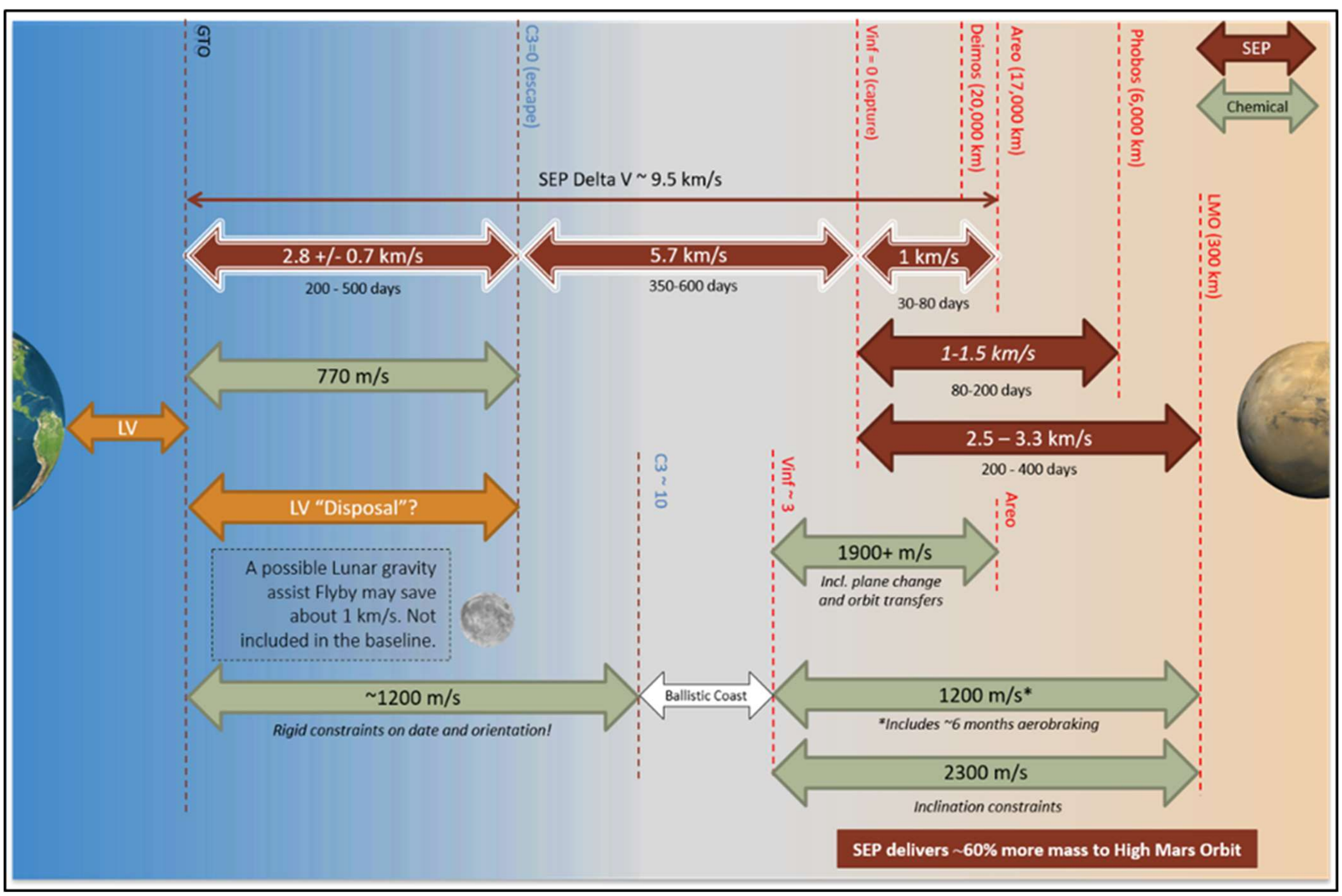


Figure 6: Notional mission design options for small spacecraft concepts to Mars via rideshare.

After researching access to space, the study examined methods to get to Mars using self-propulsion from Earth to GTO. Figure 7 is a summary of different notional mission design options and compares time of flight and ΔV for solar electric propulsion (SEP) and chemical trajectories going to various destinations. The estimated values assume a strawman spacecraft concept with a dry mass of 200 kg.

In almost every Mars expedition plan from von Braun to the present, propellant has been potentially the single heaviest expedition element [8]. A propellant trade between chemical and low thrust solar electric propulsion shows that SEP propellant mass versus dry mass delivered to Mars is an order of magnitude difference in favor of a micro-thrust electric propulsion (see figure 8 and 9).

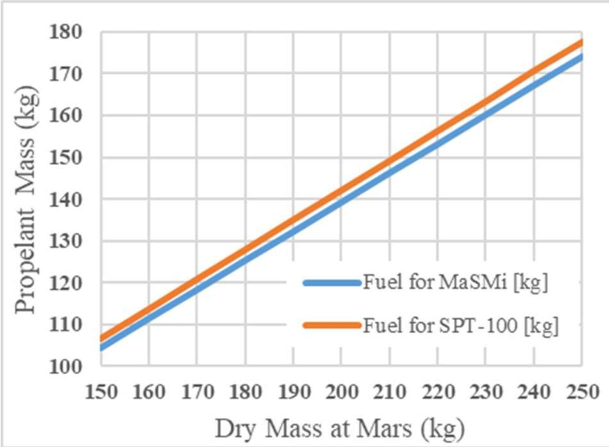


Figure 8: Electric propellant mass versus dry mass delivered to Mars

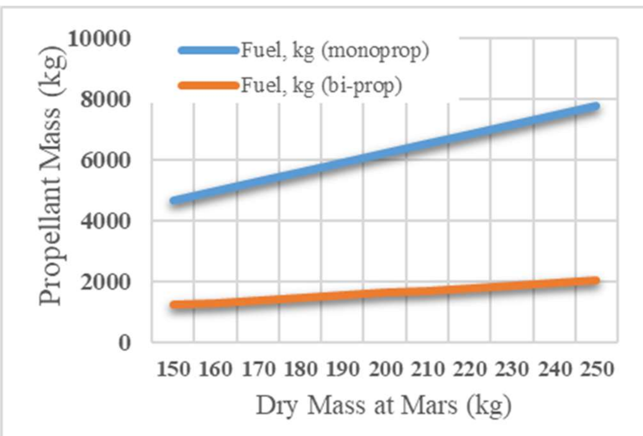


Figure 9: Chemical propellant mass versus dry mass delivered to Mars.

After the study selected electric propulsion option, the study began to investigate electric propulsion thrusters. For the electric propulsion trade options, the study examined hall and ion thrusters that have flight heritage and those that are under development, shown in figure 10. The engines considered for the trade were the Busek BHT-600, the JPL-developed Magnetically Shield Miniature hall thruster (MaSMi), Fakel SPT-100, Safran PPS-1350, L3 XIPS-25, and the Glenn Research Center developed NSTAR thruster. Considering a 200 kg strawman s/c concept to Mars high orbit, first order analysis estimated a propellant mass of roughly 160 kg. The figures of merit for the trade were propellant throughput, mass, power, cost, and heritage. The Safran PPS-1350, a variant of SPT-100, and JPL-developed MaSMi met the mission requirements of the study and were used for conceptual mission design for a trajectory from GTO directly to Mars.

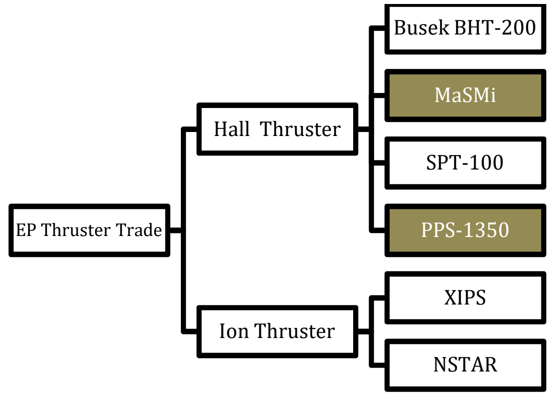


Figure 10: Electric propulsion trade space for small spacecraft concepts.

The study concluded that the benefits of a self-propelled secondary payload spacecraft to Mars are:

- Low launch costs.
- Flexibility for frequent Mars access.
- Utilization of current advances in solar electric propulsion.

4. Enhancing Technologies

During the mission concept study, technologies under development that could potentially increase the mission capability while reducing cost of the spacecraft was identified. Desired areas of where mission could gain significant benefits are:

- Telecommunications
- Propulsion
- Avionics
- Science sensors and instruments

During a period from January 2022 to December 2028, the maximum distance between Earth and Mars is 2.55 astronomical units. Telecommunications from Mars to Earth at this distance could pose a challenge for a small spacecraft. Development in power amplifiers, antenna, and radio frequency (RF) transponder would increase capability, such as a miniature klystron Ka-band amplifier [9].

Mission design analyses of a Mars-bound 200 kg small spacecraft mission concept using solar electric show a minimum propellant throughput of 120 kg, if a single engine is used. The MaSMi Hall Thruster Program at JPL, which pioneered the first low-power magnetically shielded Hall thruster in 2012, has aimed to develop a low-power high efficiency Hall thruster capable of >100 kg Xe throughput [10].

5. Mars Small Spacecraft Mission Concepts

The study consisted of two parts as shown in figure 11. The first part investigated the science opportunity and technical feasibility of getting small spacecraft to Mars. The first part confirmed that it is technically feasible to send a small spacecraft to Mars from Earth GTO using solar electric propulsion. The on-going second part of the study is investigating orbiter and lander mission concepts. This paper will provide a brief overview of an orbiter concept called Areostationary Trace Gas Localizer (see figure 12) and a surface landing spacecraft concept called SHIELD (see figure 20).

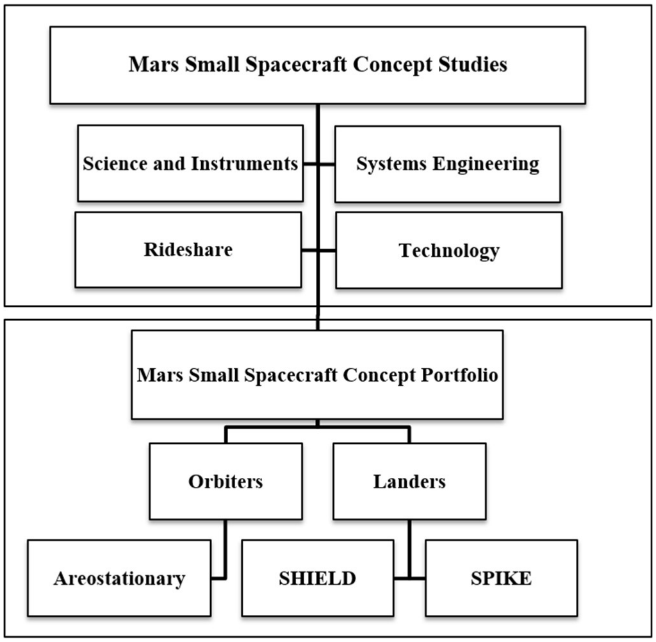


Figure 11: Mars small spacecraft concept studies hierarchy.

Areostationary Trace Gas Localizer Concept

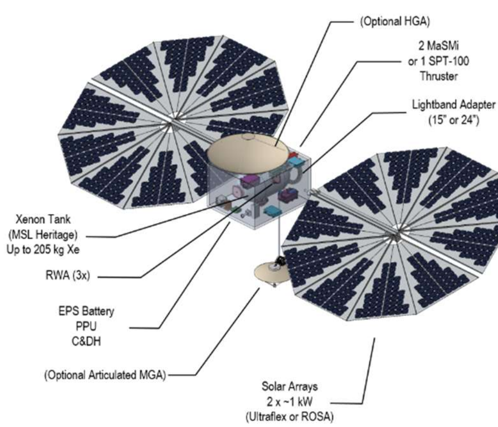


Figure 12: Mars Areostationary spacecraft concept

Spacecraft Concept Dry Mass:	**< 220 kg**
Target:	Mars Areostationary Orbit
Configuration:	Single spacecraft; possible constellation
Propulsion Type:	Solar electric propulsion
Risk Class:	D
Expected Life on Orbit:	3 years
Launch	Secondary Payload on ESPA Grande
Science Payload	Spatial Heterodyne Spectrometer

Table 1: Areostationary spacecraft concept features

The science objective for the Mars Areostationary concept is to localize the sinks and sources of methane and their daily and seasonal variability (see figure 12). The data product the spacecraft concept could produce is daily maps of methane and water fluxes while pointing nadir at Mars and collecting spectra using a spectral heterodyne spectrometer (SHS).

The motivation for this work is the long-lasting puzzle of spatial and temporal variability in methane measurements on Mars, which raise the question of whether these oscillations in methane abundance are due to biological or geochemical activity. To find an answer, it is pivotal to observe the same large region of Mars continuously with gas spectrometers that have been fine-tuned to detect methane and water and some of their isotopologues. Isotopologues measurements are also needed as they can help infer the nature of the sources of methane.

The operational scenario of the SHS instrument consists of two modes, course and fine, detailed in figure 13. During course mapping mode, a daily survey consisting of 119 km x 119 km patches will be scanned using SHS. If methane is detected, further analysis may be performed during fine mapping mode which has a ground sampling distance of 17 km x 17 km.

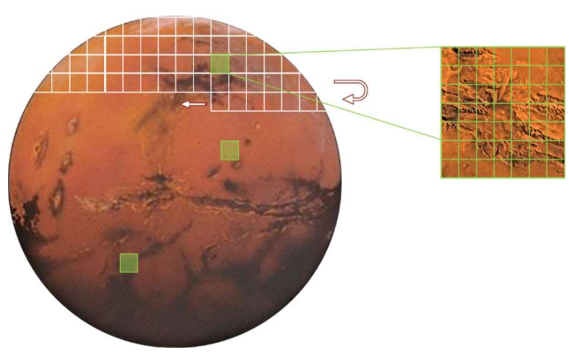


Figure 13: Science mode operational scenario using the SHS to localize methane on Mars.

Sub-System	Parameter
ΔV	Spiral out: 1.6 km/s Cruise: 5.7 km/s Spiral in: 0.9 km/s
Telecom	Direct To Earth: Ka-band dedicated, X-band backup and DFE. 1 meter HGA, 100W TWTA Ka Band, Universal Space Transponder
Propulsion	2x MaSMi Hall Thrusters
ACS	0.2 deg – driven by HGA req.
Power	2.0kW (BOL) lightweight solar array Secondary batteries – 250Wh capacity
C&DH	Dual-Core LEON3FT (SPHINX), 100MHz, 8GB NAND Interfaces: RS422, SPI, I2C, Spacewire, GPIO, UART
Mechanical	1.1m x 1.2m x 1.4m (ESPA Grande)
Payload	Spatial Heterodyne Spectrometer Multispectral Wide Field Imager

Table 2: Areostationary concept flight system parameters

To access space, the spacecraft concept will launch as a secondary payload to GTO with a wet mass of 350 kg attached to an ESPA Grande [11], payload adapter, as shown in the concept rendering (see figure 15).

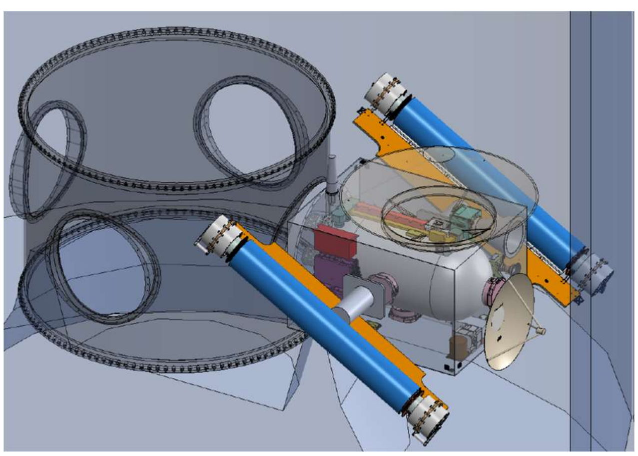


Figure 14: Areostationary concept attached to an ESPA Grande adapter.

Once at GTO, the spacecraft will spiral out for 7 months of to get to C_3 = 0 km^2/s^2, see figure 16. During the s/c spiral from Earth, the spacecraft will gain a ΔV of 3.3 km/s and use 65 kg of xenon.

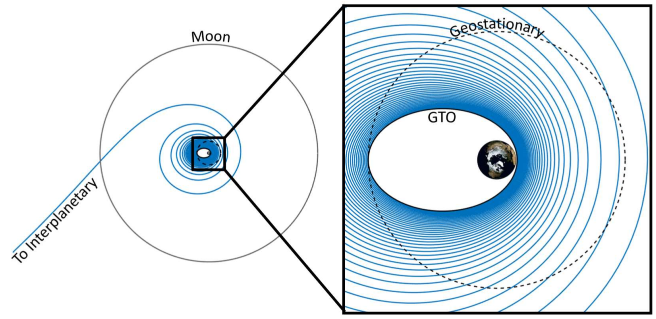


Figure 15: Conceptual mission design for SEP powered small spacecraft from GTO to Earth escape.

From a characteristic energy (C_3) of 0 km^2/s^2, the spacecraft concept will begin the interplanetary low-thrust transfer, shown in figure 17. The duration is estimated at 15 months, with a change in velocity of 5.7 km/s, and 85 kg of xenon consumed. Once at Mars, the s/c concept will spiral in to an Areostationary orbit, from which point in time observations can already start if needed but do not represent the primary science operations target (see below figure 17).

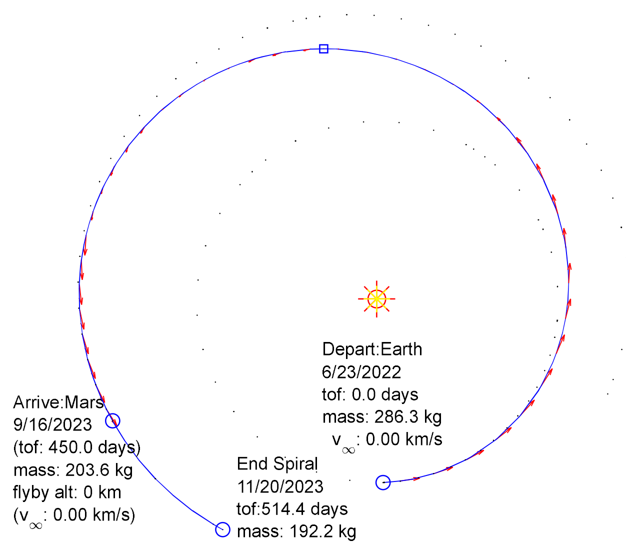


Figure 16: Cruise phase of conceptual mission design of Mars bound small spacecraft.

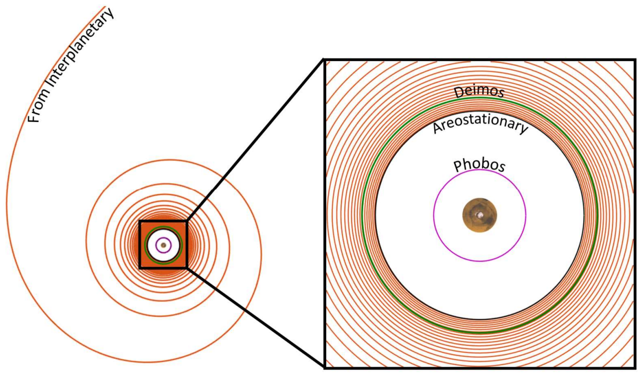


Figure 17: Spiral down trajectory into Mars Areostationary orbit.

The last cruise phase will have a ΔV of 1 km/s, use 10 kg of xenon, and deliver ~190 kg of payload to Mars (see figure 18).

Once the spacecraft concept has spiraled down into areostationary orbit, the spacecraft will begin to conduct the primary science and downlink the data back to the deep space network. Notionally, once the spacecraft has completed a checkout mode on orbit, it will begin one of three phases based upon the illumination of the surface of Mars.

Table 3: Mars Areostationary concept on-orbit modes.

Mars Areostationary Concept		
On-orbit mode	***Duration***	***Day/Night***
Spectrometer Science	8 hours	Day
Imaging	16 hours	Day and Night
Downlink	8 hours	Night

Table 3 outlines the three different on-orbit modes. Spectrometer science is the primary science phase and occurs when Mars is illuminated. The study assumes an illumination period of 8 hours. During nighttime on Mars, the spacecraft could downlink that sols spectra and images as shown in figure 19.

SHIELD Mission Concept Overview

The study has two target areas to conduct science investigations; Mars orbit, and the Martian surface and/or subsurface. Conventional methods of landing payloads on the surface of Mars rely on a multistage entry/descent/landing (EDL) approach with separate technologies to address each of these stages:

- heatshields for entry
- parachutes for descent
- and thrusters/airbags/skycranes for landing

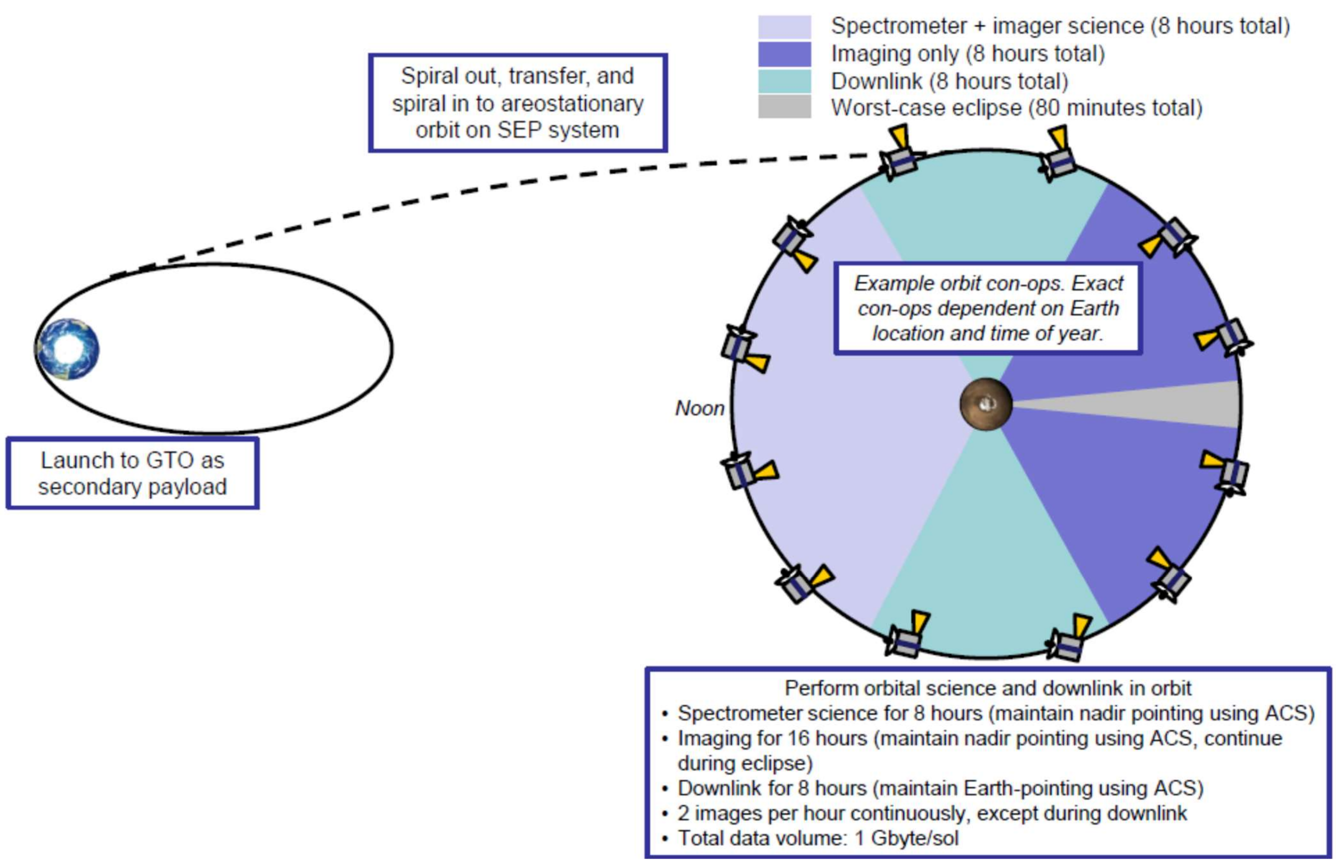


Figure 18: Mars Areostationary spacecraft concept of operations.

As a result, conventional EDL technologies are typically massive, complex, and expensive. A simplified EDL technology, particularly one that is well suited to small landers, could drastically reduce the cost and increase the frequency of missions to the surface of Mars.

In order to reduce the cost of landing small payloads on Mars, a new technology has been developed: the Small, High Impact Energy Landing Device (SHIELD), see figure 20.

SHIELD addresses all three stages of entry/descent/landing with a multifunctional structure that performs as

- A heatshield during entry
- An aerodynamic decelerator during descent
- An attenuator and energy absorber during landing

Benefits of using SHIELD is that the landing decelerations are significantly higher than more conventional Mars EDL technologies, roughly 9,000 m/sec^2, or 900 g. As a result, not all payloads will be compatible with SHIELD.

But for those compatible payloads with SHIELD, it provides access to the surface of Mars at substantially lower cost and with a substantially greater frequency of opportunities. SHIELD is particularly synergistic with small cubesat-like instruments and mission concepts. The low mass of SHIELD-based missions allows these missions to be flown more frequently as secondary payloads on larger missions, small dedicated missions, and in large numbers (>10) on larger dedicated missions.

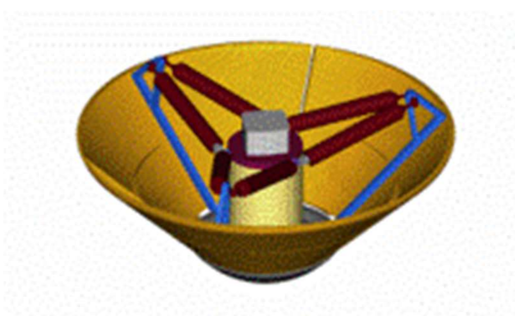


Figure 19: SHIELD concept, SHIELD is a mechanical impact-absorbing device designed to deliver small payloads to the surface of Mars.

SHIELD incorporates energy absorbing materials and mechanisms that provide the following functions at landing:

- Dissipation of the kinetic energy associated with terminal velocity, minimizing/eliminating any "bounce" that could pose a threat to the hosted hardware.
- Tuned deceleration of hosted hardware to keep the flight loads below the designed loads, insuring hardware survival after landing.
- Opening of the aerodynamic fore-body structures to provide access to the surface of Mars.

The SHIELD system is aerodynamically passively stable and has no parachute deployments, no heatshield jettison, and no backshell separation. As a result, there is no need for a guidance, navigation, and control system, further reducing cost and mass.

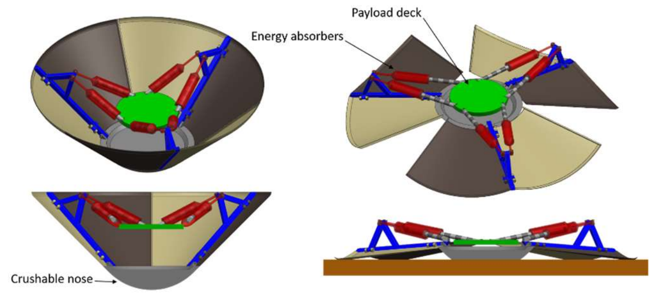


Figure 20: SHIELD conceptual configurations.

6. Conclusion

The study determined that small spacecraft could get to Mars from Earth GTO as a secondary payload. A self-propelled flight system could fit within the ESPA mass and payload constraints. The study identified several high-priority science investigations that could be performed with small spacecraft. The study concludes that small affordable spacecraft mission from Earth GTO to Mars are technically feasible, could fit within the cost constraint of < $300 million, and have the potential to deliver high-grade science complimentary to large Flagship missions.

7. Acknowledgment

The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. The information presented about potential mission concepts is pre-decisional and is provided for planning and discussion purposes only.

8. Nomenclature

C_3	Characteristic Launch Energy
COTS	Commercial Off the Shelf
DTE	Direct to Earth
EELV	Evolved Expendable Launch Vehicle
ESPA	EELV Secondary Payload Adapter
g	Acceleration due to Earth's Gravity
GTO	Geosynchronous Transfer Orbit
HGA	High Gain Antenna
JPL	Jet Propulsion Laboratory

kg	kilogram
LEO	Low Earth Orbit
MaSMi	Magnetically Shielded Miniature Hall Thruster
MEPAG	Mars Exploration Program Analysis Group
MSR	Mars Sample Return
S/C	Spacecraft
SEP	Solar Electric Propulsion
SHIELD	Small High Impact Energy Landing Device
SHS	Spatial Heterodyne Spectrometer
Sol	Mars day
TGO	Trace Gas Orbiter

9. References

[1] Missions | Mars Sample Return. (2018, October 10). Retrieved from Mars Sample Return: http://www.jpl.nasa.gov/missions/mars-sample-return-msr/

[2] Adams, L. J. (1994). Technology for small spacecraft. *Committee on Systems Integration for Project Constellation, and Ebrary*, *Inc*. Washington, DC.

[3] Mars Exploration Program Analysis Group (MEPAG), "Mars Science Goals, Objectives, Investigations, and Priorities: 2018 Version", 2018.[4] The National Academy of Science (2018). *An Astrobiology Strategy for the Search for Life in the Universe*. Washington, DC: The National Academies Press.

[5] Firefly Aerospace. (2018, 10/10). Firefly Aerospace Payload Users Guide. Retrieved from Firefly Aerospace: http://fireflyspace.com/assets/files/Firefly%20Aerospace%20Payload%20User's%20Guide.pdf

[6] M. Galik, "Space Test Program (STP-1) -- First of its kind!", in *18th Annual AIAA/USA Conference on Small Satellites*, 2004.

[7] Space and Missile Systems Center Launch Systems Enterprise Directorate (SMC/LE), "Evolved Expendable Launch Vehicle Rideshare User's Guide", El Segundo, CA, 2018.

[8] Portree, D. S. (2001). *Humans to Mars*. NASA.

[9] B. Vancil, C. Osborne, M. Caplan, and D. Radovich, "Miniature Klystron for CubeSats," 2018.

[10] Conversano, R. W., Lobbia, R. B., Tilley, K. C., Goebel, D. M., Reilly, S. W., Mikellides, I. G., and Hofer, R. R. (2017). "Development and Initial Performance Testing of a Low-Power Magnetically Shielded Hall Thruster with an Internally-Mounted Hollow Cathode." 35th International Electric Propulsion Conference, (p. 3). Atlanta.

[11] Moog Space and Defense Group. (2018, October 10). ESPA Ring. Retrieved from Moog: https://www.moog.com/content/dam/moog/literature/Space_Defense/spaceliterature/structures/SAIS_ESPA_Ring_Rev_0712.pdf

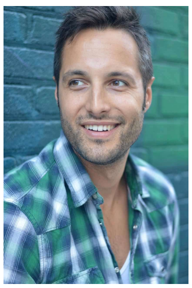
Biography

Nathan Barba *is a systems engineer with the Advanced Design Engineering Group at the Jet Propulsion Laboratory. Nathan received his B.S. in mechanical engineering from Arizona State University. While at Arizona State University he supported the NASA selected mission LunaH-Map as a systems engineer supporting the spacecraft harness and instrument. His current focus at JPL is small spacecraft system engineering, project formulation, and instrument development.*

Tom Komarek *is a Sr. Engineer in the Mars Program Formulation Office of the NASA/Jet Propulsion Laboratory (JPL) in Pasadena, CA. Tom has recently led the Mars Program Advanced Development Team (ADT) that developed requirements and interfaces between the existing Mars projects and possible future Mars Sample Return projects. His past assignments included deputy project manager and chief engineer for past Mars orbiters, with special emphasis on laser communications, and autonomous navigation. During his tenure at JPL, he also managed the spacecraft radio and antenna section. His interests and work also include system engineering, mission formulation, spaceborne radar, radio science investigations and planetary small spacecraft, especially small spacecraft targeted for Mars and its moons. Tom has a BSEE and MSEE degrees from the Czech Technical University in Prague, and MSEE/Professional Engineer degree from the Technical University of Delft, The Netherlands.*

Ryan Woolley *received a B.S. in Physics-Astronomy from Brigham Young University, a M.S. in Astronautical Engineering from USC, and a Ph.D. in Aerospace Engineering from the University of Colorado. He has been with JPL since 2005. Ryan began his tenure as a systems engineer* *in the Mars Mission Concepts group and has since transferred to the Inner Planets Mission Analysis group. He has worked on nearly all aspects of the Mars Sample Return campaign and has developed many tools to design evaluate mission designs and architectures.*

***Lou Giersch** has been with JPL for more than 10 years, where he currently works in the Entry, Descent, Landing and Formulation Group. He has previously worked in the deployable structures group at JPL, and he received his PhD in Aeronautics & Astronautics from the University of Washington in Seattle, WA in 2005.*



***Vlada Stamenković** "My name is Dr. Vlada Stamenković, I am a Research Scientist at the NASA Jet Propulsion Laboratory, where I explore the co-evolution of planets and life from origins until the bitter end—on Earth, in our solar system (with a big focus on Mars Science), and on rocky exoplanets. With the goal to understand what makes a planet truly habitable (more than just liquid water) and also inhabited.*

To achieve this goal, I study the fundamental geodynamical principles behind mantle convection, tectonic evolution, and the formation and transport of volatiles through mantle and crust driven by volcanism and low temperature processes such as, e.g., serpentinization and radiolysis of water – and explore how such planetary processes co-evolve with a planet's fluid envelope (groundwater, oceans, and atmosphere), its redox gradients (from hydrogen to oxygen), microbial organisms, and bigger bugs like us humans.

Next to trying to understand theoretically how planets and life co-evolve, I am discovering geophysics-life connections in the underground of our own planet and use my days to enable next generation missions to explore the Mars subsurface in the quest for life and resources—helping to enable Humans live on the Red Planet and to get us closer to the stars above and within.

***Mike Gallagher** has been with JPL since 2001, where he currently works in the System Integration, Test and Launch Systems Engineering Group as a Sr. Launch Systems Engineer. He has been supporting the Ridesharing and Small satellite community since 2005. He received his BS and MS in Aerospace Engineering from the University of Colorado, Boulder in 1980 and 1982, respectively.*

***Charles (Chad) Edwards, Jr.** is the Manager of the Program Formulation Office in the Mars Exploration Directorate at the Jet Propulsion Laboratory, where he also serves as the Directorate's Chief Technologist. He received an A.B. in Physics from Princeton University and a Ph. D. in Physics from the California Institute of Technology.*